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THE ROLE OF ADAPTIVE SUPPLEMENTAL VISUAL CUING
IN FLIGHT SIMULATION

BY

EDDY RAY BILLMAN

B.S., United States Air Force Academy, 1978

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Psychology
in the Graduate College of the
University of Illinois at Urbana-Champaign, 1987

Urbana, Illinois

THE ROLE OF ADAPTIVE SUPPLEMENTAL VISUAL CUING
IN FLIGHT SIMULATION

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The utility of adaptive visual cues for instructing an approach-to-landing

task in a personal computer-based flight simulator was tested. Flight naive

subjects in a control group trained with reference to a visual display that

consisted of horizon, runway outline, runway centerline and touchdown

aimpoint. Two experimental groups trained with glidepath and heading cues

augmenting the display either constantly or adaptively. A simulator-to-

simulator transfer-of-training design found no significant differences between

instructional methods. Because other research had found adaptive cuing to be

beneficial in transfer, implications of the differences in design

considerations such as visual display field of view and the amount or content

of subject pre-training is discussed and related to this study.

ACKNOWLEDGMENTS

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Introduction

Flight Simulators in the Eighties

Simulators in commercial and military aviation have seemingly become commonplace in training and for maintaining flying proficiency. Over a decade ago, Hopkins (1975) provided a checklist by which one could evaluate the utility of simulators for training. He stated that the claimed advantages of simulators were in the areas of cost, safety, efficiency, and effectiveness.

Today, simulators are enhancing flying safety in a number of ways. Pilots receive intensive procedural training that would otherwise be cost prohibitive in expensive aircraft. Simulators are used to train pilots to deal with potentially catastrophic malfunctions that could not be safely practiced in the air. Finally, simulators allow accident investigators to recreate incidents to help identify causes.

Innovations in efficiency and effectiveness also show promise. The direction training courseware has taken in recent years seems to answer Hopkins' (1975) call for attention to how the simulator is used. While the crusade for improved physical fidelity in visual and motion cuing systems continues, emphasis grows to include simulation devices in an integrated systems approach to training. Both the Navy and the Air Force are currently seeking restructured training programs that give synthethic training devices equal importance with academic courseware and in-flight training when determining training requirements (Spears & Isley, 1986). Extensive reviews of the role of simulation recommend a de-emphasis of physical fidelity and more focus on an understanding of skill acquisition, basic behavioral processes, and instructor techniques (Semple, Hennesey, Sanders, Cross, Beith & McCauley, 1981; Jones, Hennesey & Deutch, 1985). While this re-orientation is encouraging, much remains to be done to shift future development of

simulation from technology driven to requirements driven.

The cost-effectiveness of simulators has become uncertain. Hopkins (1975) warned that the quest for fidelity in simulator technology would soon drive their cost to astronomical levels. That has proven to be true. However, while today's simulators commonly cost millions of dollars, the cost of today's counterpart aircraft has skyrocketed to the tens of millions of dollars. Relatively speaking, simulators generally remain much less expensive than their counterpart aircraft. However, rising costs in simulation technology has had an adverse effect on other segments of the aviation industry. While advances in simulation have been advantageous to commercial and military aviation, the same advances have been put out of the reach of small business and light, general aviation aircraft users. Comparable high-technology simulators for general aviation may easily exceed the cost of the counterpart aircraft. If simulators in general aviation are to have a meaningful future, their development must follow a different path.

A Need for Simplicity

The University of Illinois at Champaign/Urbana has been involved in an innovative program of research over the past few years to explore improvements in general aviation flight training. A major portion of this research effort is concerned with identifying potential uses of small computers for instruction, evaluation, and simulation applications within general aviation flight training. The impetus for such a program came about from two important observations. First, the rapid evolution of the computer had placed the power, capabilities, and flexibility of yesterday's mainframe computers into today's affordable personal computer. Secondly, major advances were being made in flight training methodology by the military and commercial aviation, and still more promising technologies were on the horizon. The connection was made between the need and the resources, and the question asked: Could an

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effective training device for general aviation be developed around a personal computer?

The PC-Based Landing Trainer

This paper reports one of the efforts in the University of Illinois research program to develop personal computer (PC)-based training aids for general aviation flight instruction. The goal of the study was to develop a simple, inexpensive, PC based part-task simulator to teach beginning flight students an approach-to-landing task. To assess the feasibility of such a training device, four fundamental issues needed to be resolved: Can a personal computer support the features of a simulator necessary to provide flight training? Can it be shown that learning on some major dimension has occured as a result of training on the device? Can techniques be employed that actually enhance learning - techniques not available with in-flight instruction? Can the learning accomplished in the computer-based trainer show positive transfer to the aircraft?

The capabilities of modern personal computers show promise in handling many of the functions necessary for an effective part-task simulator. Storage capacity of approximately ten megabytes should be sufficient for data collection. Actual program code required to drive a dynamic, real-time simulation in three dimentional space is considerable, but should not exceed the capacity of most computers with at least 512K RAM. A PC-based simulator would also require that analog or digital aircraft controls be constructed, and that a hardware/software interface be designed to combine computer and controls. The most difficult task for the personal computer in simulation is generating the visual display. The complexity of the visual scene possible on a typical personal computer will probably be severely limited. Generating real-time graphics for a simulated visual scene requires rapid processing of

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the equations that define the environment. While most PC's are capable of impressive static graphics scenes, animating complex scenes into frames that change frequently enough to avoid serious control/display lag is impossible. Since computer processing power is finite, scene complexity must be compromised to allow for faster scene updates. Finding the balance between visual scenes with rich enough environments to promote learning and frame rates fast enough to satisfy human perceptual requirements will prove to be challenging.

The design of the visual display for the PC-based landing trainer presents a considerable challenge. However, little guidance exists to suggest an optimal display. Some work has been done that addresses effects of delay in visual and motion cuing systems for simulators , but the detrimental effect that temporal lag has on performance seems to be task specific (Semple, et al., 1931). In light of the considerable variation in lag/task combinations, a conservative value for maximum display lag of 100 milliseconds seems reasonable. With a standard video display device contributing approximately 16 milliseconds of delay, 84 milliseconds remain for the computer to calculate each scene, or a frame rate of 12 hertz.

The number of features that can be represented at 12 hertz is minimal. While more powerful commercial simulators are free to display as realistic a scene as desired, the contents of the PC-based simulator must be carefully chosen. An optimal design strategy for visual displays remains elusive, and the lack of guidance leads most simulator designers to maximize realism in the scene in hopes of capturing whatever it is that promotes learning. Some studies, however, demonstrate that effective training can be accomplished on displays with relatively low levels of realism.

Westra (1982) trained students to land on aircraft carriers in the simulator using only a point light source outline of the carrier in the

display. Westra concluded that the additional benefit of solid surfaces appears to be marginal. Eisele, Williges, and Roscoe (1976) compared various combinations of runway environment elements such as runway outline, centerline, touchdown zone marking, ground texture, and artificial landing guidance cues to determine the minimum set of visual image cues sufficient for spatial orientation during aircraft landing approaches. Their work suggests that a relatively low level of detail is sufficient to orient oneself for landing an aircraft. Lintern (1980) taught subjects to fly an approach-to-landing task using a display consisting of runway outline, centerline, horizon line, and aiming bar. Although highly skeletal, Lintern's display was successful in training subjects to land the simulator. More importantly, learning in Lintern's simulator transfered positively when measured in-flight. In an extensive review of current simulation issues, Jones et al. (1985) conclude that low realism visual displays are successful when designers concentrate on the meaning, or cue value, of stimuli present, equating functionally, rather than objectively with the operational system. The literature suggests that a low physical fidelity display such as the one used by Lintern (1980) should be sufficient for an aircraft landing trainer.

Computer-based training devices show promise in their ability to teach at least some classes of skills. Trollip (1977) successfully trained student pilots to fly holding patterns using a computer-based display, indicating that complex procedural skills can be taught by computer if the appropriate cues for performance are adequately simulated. Lintern and Weinstein (1987) used a microcomputer simulation to train military air-intercept control skills. Subjects in their study learned to identify visually presented stimuli, assess relative bearing between stimuli, and predict the heading required for stimuli to intercept each other. Training conducted on PC-based devices can be

successful if designed properly to provide the cues, stimuli, and responses necessary to promote learning. However, it is also important to ask whether modern computer technology can allow the use of special features that go beyond merely mimicing aircraft in simulation, to enhance or accelerate learning. The most far reaching benefits may lay in the computer's ability to enhance the learning environment.

Capitalizing on Personal Computers: Enhancing Learning

It has been established that effective learning can be accomplished through the use of computers. Evidence also exists that suggests that computers can be used to enhance learning. The history of flight simulators is characterized by advances in technology designed to increase the degree to which the simulator physically and psychologically duplicates aircraft flight (Caro, 1973; Hopkins, 1975, 1976; Valverde, 1973; Willeges, Roscoe & Williges, 1973). In fact, almost all current technology continues to focus on more realistic visual, motion, and proprioceptive cuing systems (Lintern, 1986; Semple et al., 1981). Little work has been done to determine the utility of synthethic training devices in aiding understanding of system dynamics, interdependencies of system components, or physical and geometric relationships critical to the system. However, a few studies are documented that show the potential for technology to move simulation beyond duplication toward enhanced and accelerated understanding.

Lintern (1980) used augmenting cues on a simulated landing display to teach subjects the proper visual glidepath for landing approaches in a small aircraft. He found that simulators could be useful in presenting information that facilitates learning and understanding of the task, even though the information was not actually visible in the natural visual world. If the information is used to focus attention on some critical aspect or relationship of the task, the augmentation is beneficial.

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In a similar study by Coblitz, Verstegen & Hauck (1983), the graphics capability of a computer based simulator was used to present specially designed information to pilot subjects. Coblitz and his colleagues constructed displays that depicted aircraft energy states, velocity vectors, and other relative information not normally visible to the pilot. Results indicated that subjects gained a better understanding of the physical forces affecting their aircraft when presented such information.

Eberts and Schneider (1985) used computer generated imagery to train subjects to internalize the dynamics of a second-order system. They found that visual augmenting cues provided during a manual tracking task could affect the development of the subjects' internal model of the system. Subjects trained with cues designed to aid the understanding of the system dynamics were able to manipulate their internal model of the system to solve system problems even when the cues were no longer present.

The studies by Lintern (1980), Coblitz, et al. (1983), and Eberts and Schneider (1985) are examples of how augmenting a task can be very effective where performance is dependent on an understanding of system dynamics or geometric concepts. Unfortunately, application of these techniques has not yet found widepread acceptance in the training community. Nonetheless, augmentation in simulation remains a promising concept that is well supported by empirical studies. A brief review of studies relevant to augmentation can help explain its potential.

Augmenting Feedback. Computer-based simulators are capable of presenting nearly anything a designer deems suitable. Deciding what information should be added to the task in the form of augmenting feedback has direct relation to the success of the feedback.

Lincoln (1954) conducted a series of experiments designed to assess the

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benefits of performance feedback in learning a motor task. Subjects were
required to rotate a hand crank at a specific constant rate, measured in
revolutions per minute. A spot of light on the apparatus moved left or right
of a marked reference point to indicate slow or fast deviations from the
desired rate of movement. Lincoln found that subjects trained without the
visual feedback performed better tnan those trained with the visual feedback
when it was removed. From his results, Lincoln concluded that learning a task
with feedback present hindered performance on the tasks when feedback was
later removed.

In contrast, Karlin and Mortimer (1962) found positive benefits of
performance feedback on the same type apparatus. Instead of a point light
source as performance feedback, Karlin and Mortimer displayed an RPM guage to
subjects to indicate both direction and relative amount of deviations.
Further study by Karlin and Mortimer (1963) compared the effects of visual,
verbal, and auditory feedback on learning a compensatory tracking task and
again found feedback to be beneficial. Karlin and Mortimer concluded that
augmenting cues were most effective in transfer when they functioned as
incentives and in defining standards of performance, and least effective when
they provided information for guiding immediate behavior.

Another study undertaken at about the same time seemed to contradict the
conclusions of Karlin and Mortimer. Bilodeau and Rosenquist (1964) used an
auditory buzzer as performance feedback on a compensatory tracking task.
Using different intervals of reinforcing clicks as augmenting guidance for on-
target performance, they found transfer performance better for subjects
trained without the cues present.

Gordon and Gotleib (1967), and Gordon (1968) conducted research with
augmenting feedback for rotary pusuit tracking, centering their work around a
comparison between on-target visual feedback and off-target visual feedback.

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The results of their studies suggest that both off-target and on-target visual feedback are superior to no feedback in training, but off-target augmentation yields the best transfer performance.

Integrating all the literature concerning augmenting cues for perceptual-motor skill training suggests that feedback is beneficial under certain conditions. First, the cues presented must not promote a dependency on their use. When subjects perform the task by reference to the cues and disregard the intrinsic information inherent in the task, dependency on the cues has developed. Off-target cuing is superior to on-target cuing because it deters dependency. Bilodeau and Rosenquist's (1964) on-target cuing appeared to motivate the subject to perform in such a way as to maximize the presence of the cue, possibly detracting from relevant stimulus/response relationships. Gordon and Gotleib's (1967) off-target cuing served more of an alerting function, motivating the subject to concentrate on improving performance. With off-target cuing, good performance minimizes the presentation of the augmenting cues, and dependency is less likely.

Additonally, as Karlin and Mortimer noted, cues should define standards of performance and not merely serve to guide immediate behavior. Lincoln's (1954) point light source cues failed to define standards for the subjects and they likely used the cues to guide their behavior during training. Cues should be constructed so that they direct the subject's attention to the information which stems from matching responses with already available exteroceptive cues. Therefore, the choice of cues is just as important as how they are presented. A cue that only alerts the operator to slow down or move to the right, without highlighting the system state, variable, or component relationships that precipitated the correction, does little to aid in the operator's understanding of the task.

The above discussion on augmentation suggests that learning can be enhanced if the cues cues are carefully chosen and presented in the correct fashion. One technique of presenting cues that avoids dependency is to present them adaptively.

Adaptive Training. Adaptive training is training in which the problem, the stimulus, or the task is varied as a function of how well the trainee performs. Through the logic of the training program, the trainee, or subject in an experimental setting, is presented with a level of difficulty commensurate with the individual's capabilities at that point in time. Difficulty is not allowed to increase until proficiency at the present level is attained. Thus, adaptive training allows each trainee to progress from easy to difficult at the individual's maximum pace.

The benefits of adaptive training logic remain somewhat questionable although a good deal of literature exists that seems to support its use (Kelly, 1969; Caro, 1969; Cote, Williges, & Williges, 1981; Johnson and Haygood, 1984). In an extensive review of the literature, Lintern and Gopher (1978) concluded that although adaptive training logic had been used successfully in several studies, it probably could not be applied universally to all motor skill training situations.

Specifically, manipulations of response variables such as system order, lag, gain, or stability have been found to disrupt rather than facilitate skill acquisition. Manipulations of perceptual variables such as forcing functions that affect the displacement, velocity, or acceleration of a tracking target are reported by Lintern and Gopher (1978) as only slightly more encouraging than response variable manipulation. However, the data related to feedback variables show promise for adaptive manipulations. Feedback that supplements intrinsic information about the effects of responses can simplify a control task, thereby creating a manipulation of difficulty.

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Purpose of the Study

The literature cited thus far suggests several important points. First, personal computers show potential in meeting the software and hardware requirements of a general aviation flight simulator. Secondly, perceptual-motor skill should be trainable on such a PC-based device. Also, the incorporation of augmented feedback and adaptive training logic should be successful on a PC-based trainer. Finally, learning accomplished on a PC-based trainer should positively transfer to the aircraft.

In the present study, the benefits of visual augmenting cues in teaching subjects an approach-to-landing task in a small aircraft simulator are investigated. The study is similar to research done by Lintern (1980) in which visual cues defining proper glidepath angle and heading were added to a computer generated visual display. The work reported here reflects as attempt to duplicate Lintern's results while transitioning from the expensive, complex, commercial apparatus used by Lintern to a more economical, simple, compact station comprised of personal-size microcomputers and desktop video displays.

The PC-based landing trainer is capable of supporting a visual display with the amount of detail found in Lintern's study. When horizon line, runway outline, runway centerline, and aiming bar are programmed into the landing display, the simulator calculates the three dimensional perspective of the elements and draws them on the screen at approximately 15 hertz. With augmenting cues added to the display, the simulator slows to approximately 12 hertz, the value selected as the minimum acceptable for the study. Additional scene elements such as texture gradient or other objects are not possible without slowing the simulator further.

Landing an airplane is one of the most difficult phases of flight

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training. Proficiency in landing depends on perceptual judgments that are acquired primarily through repetitive practice, and as such is a process of trial and error. Properly constructed augmenting landing cues integrated into a simulator landing display should facilitate learning the landing task if: 1) students are not permitted to become dependent on the cues, and 2) the cues focus attention on aspects of the task already present in the task, but not immediately apparent to a novice (Lintern & Roscoe, 1980).

Since the task to be taught in this study is the approach-to-landing, augmenting cues selected for inclusion in the display should make some critical aspect or relationship in landing an aircraft more apparent or salient. In particular, a greater benefit should result from highlighting an aspect or relationship that is difficult to understand or internalize, but nonetheless critical to the task. Approach path angle is one such critical aspect in the landing task, and was chosen as the relationship of interest in this study. Mertens (1978) found that pilots were better at judging approach path angle than were nonpilots, suggesting that this skill is not found in novices, but comes with flight experience. Therefore, the augmenting cues must make the approach path angle obvious, without directing attention away from the angle.

Augmenting landing cues, such as those used by Lintern (1980), assist the subject in the landing task, thereby simplifying the task when they are present. In order to use the cues in an adaptive fashion, the display should present the cues only when the subject is not performing well and remove them when performance meets criterion levels, a form of off-target feedback. Novice subjects will perform below criterion early in training, causing the augmenting cues to be present. As the subjects improve, the error criterion for switching the cues on will be broken less frequently. Thus, individual improvement determines the rate at which the presentation of augmenting cues

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will decrease. As proficiency increases, the cues will appear less and less frequently, until the task can be performed without error, and therefore, without the use of the cues. Since the cues appear less frequently as proficiency increases, dependency on the cues to perform the task is unlikely.

Method

Subjects monitored a computer generated runway scene on a video screen representing the forward view from inside a simulated light aircraft. Aircraft-like pitch, bank, and power controls coupled to a microcomputer allowed subjects real time closed-loop control of the simulator. The experimental task was to fly along a visual flight path to land on the runway. Trials began from a stationary position one mile from the runway, at a speed and altitude appropriate to initiate a normal landing approach descent.

Prior to the experiment, subjects were administered a manual control skill test for possible use as a covariate in data analysis. Subjects trained in one of three experimental display conditions and under one of two conditions of training length. After training, all subjects were tested tne same criterion task. The computer collected position error data along the flight path for performance analysis.

Apparatus

A small commercial desk-top flight simulator, the ATC 510, provided the flight controls and tne flight dynamics equations for the study. A standard yoke, controlling pitch and bank, and a push-pull throttle, controlling engine power, were the only controls used. The airspeed indicator, percent engine power indicator, and artificial horizon were the only instruments provided. Although tne task was intended to be flown with reference to the computer-generated visual display, the artificial horizon was used between trials to keep tne simulator wings-level as the visual scene went blank while the computer reset to the starting point.

Analog signals representing control inputs and flight dynamics fed from the ATC 510 desk top simulator to an IBM AT personal computer. The IBM AT computer calculated the three dimensional position of the simulator and displayed the resultant visual perspective on the video display against the

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airport scene. The capabilities of the microcomputer allowed a scene refresh rate of approximately 12 to 15 hertz (see Figure 1).

The airport scene consisted of horizon line, runway outline, and aimpoint bar. Glidepath and heading cues were also provided depending on treatment condition (see Figures 2 & 3).
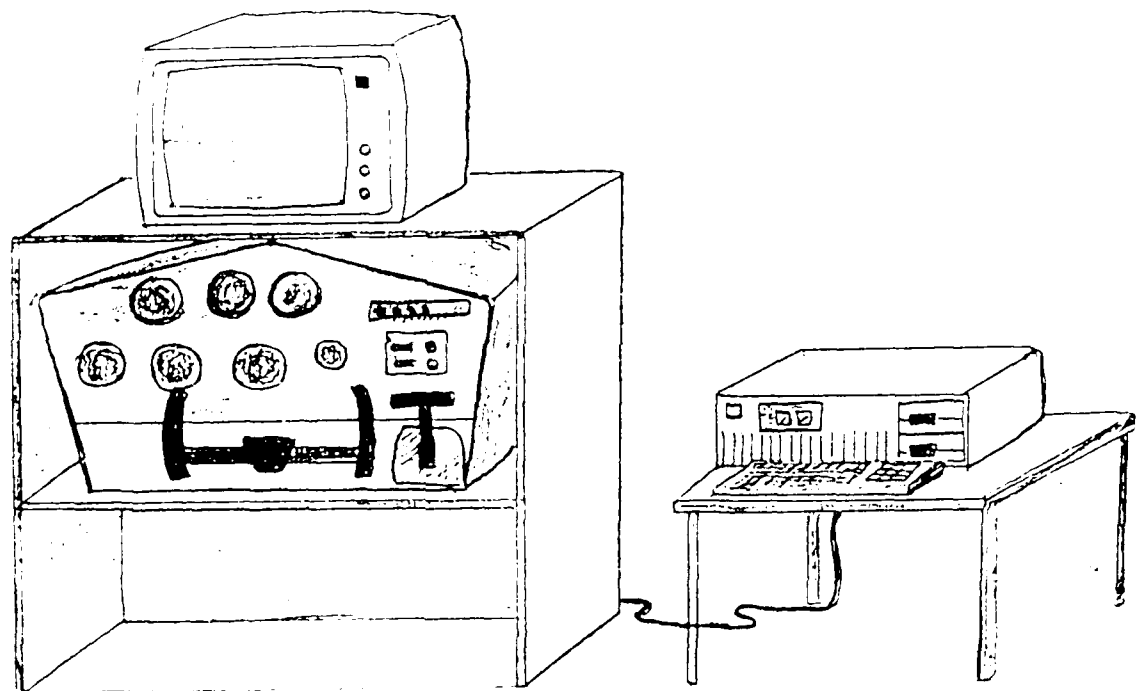

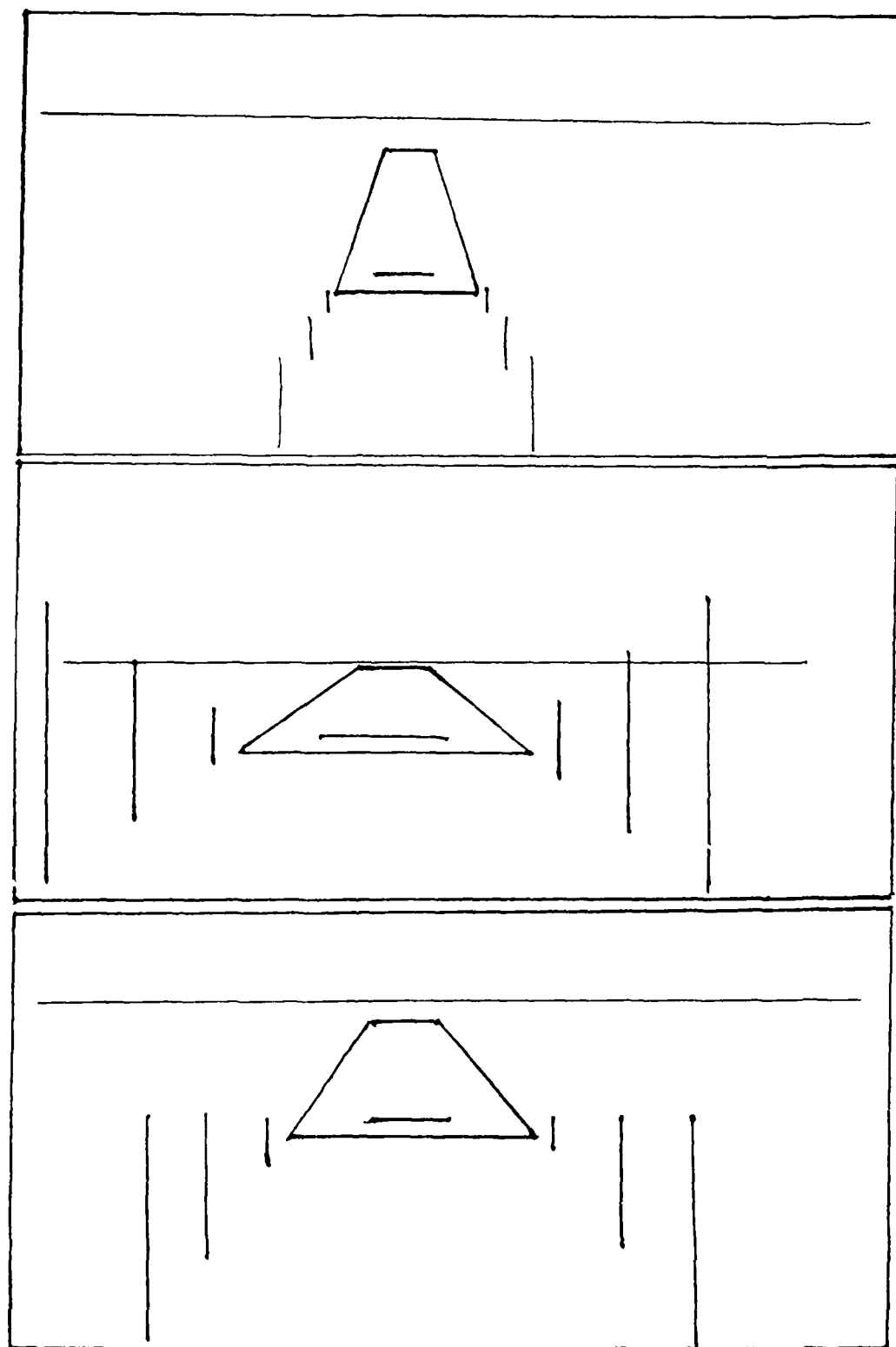Figure 1. Schematic drawing of the experimental apparatus.

Figure 2. Vertical glidepath cues depicting high, low, and normal approaches.
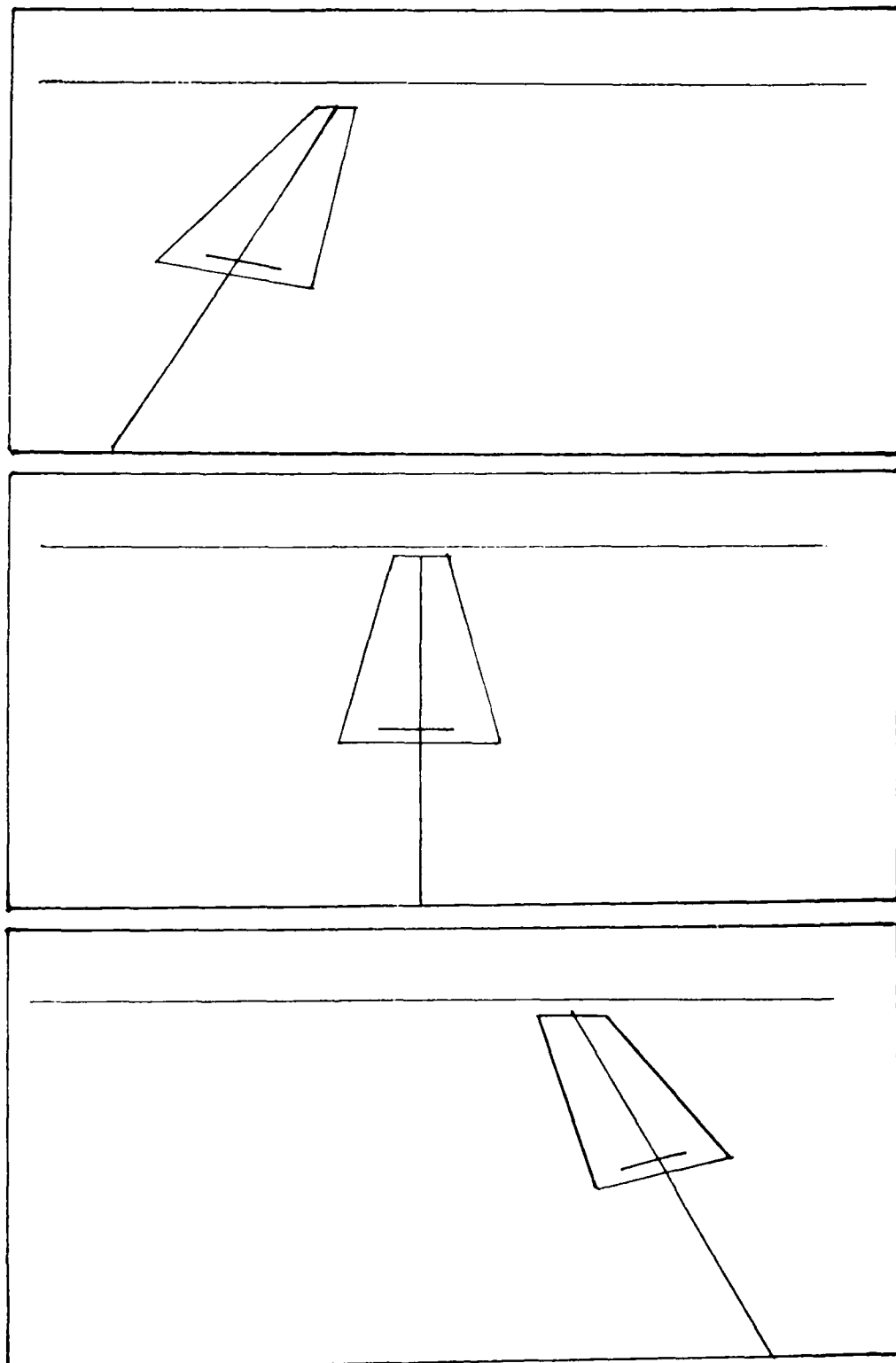
Figure 3. Lateral heading cues depicting right of course, on course, and left of course.

Subjects

Subjects were paid volunteers, solicited from announcements posted on campus. All were between 18 and 30 years of age and reported normal or corrected-to-normal vision. None had any prior formal flight training or experience. Forty-eight subjects participated in the experiment, randomly assigned to groups, then balanced between male and female.

Procedure

The first session was used to administer the manual control test for use as a covariate. Jones, Kennedy and Bittner (1981) successfully used a video game as a covariate for compensatory tracking tasks. Lintern and Kennedy (1984) used the same video game as a covariate in carrier landing research, also successfully. It was hoped that using the video game as a covariate in this study would add additional statistical power to the analysis. For a complete discussion of the procedure used in the manual control skill test, see Lintern and Kennedy (1984).

Each of the three treatment conditions were randomly assigned 16 subjects whom were balanced by sex. Half of the subjects received one block of 20 training trials in their assigned condition. The other half received an additional 20 trials in a second block of training. Two levels of training length provided a means of assessing rate of skill acquision. Thus, there were six groups total: Control Group receiving 20 training trials, Control Group receiving 40 training trials, Constant Augmented Feedback Group receiving 20 training trials, Constant Augmented Feedback Group receiving 40 training trials, Adaptive Augmented Feedback Group receiving 20 training trials, and Adaptive Augmented Feedback Group receiving 40 training trials.

In the second session, subjects were introduced to the simulator. Subjects listened to the instructions while seated at the controls of the simulator. Instructions included a basic explanation of the use of the flight

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controls and techniques for maintaining proper flight path. Subjects in experimental conditions utilizing glidepath and heading cues were instructed on the use of the cues. The experimenter flew two approach-to-landings, demonstrating the task flown both properly, and improperly with appropriate corrective action. Subjects were allowed to ask questions before beginning training.

Each subject flew one or two blocks of twenty trials, depending on group assigned. A trial consisted of one approach, beginning at the same initial point, flown to landing on the runway. To assure that each trial began with no initial error, the computer held the simulator on position freeze until the subject attained proper wings-level position, heading, and airspeed. At that time the subject was presesented a visual'GO signal and the trial began. At the completion of each trial the computer gave performance feedback to the subject. The computer displayed whether the subject had exceeded performance criterion during the trial and in which direction. Thus, the subject learned if the approach had been too high, low, or had deviated too far left or right of the runway. The subjects was instructed to use this information to improve the next trial. The goal of the training block was to learn to fly the aircraft to the runway with the minimum amount of error. Error was defined as deviation from the straight line path from starting position to the runway aimpoint.

The two Control Groups practiced the approach and landing task by reference to the runway scene consisting of only the horizon line, runway outline, and aimpoint. The remaining experimental groups had access to additional visual cues designed to enhance learning the approach-to-landing task.

The Constant Augmented Feedback Groups practiced landing with a visual

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display that had in addition to the scene used in the Control Condition, guidance cues that showed the proper glidepath during the approach and an extended centerline from the runway to provide heading guidance throughout the approach. The augmenting cues for glidepath control consisted of six vertical bars, three lining either side of the runway along the approach. The bars closest to the runway were 1/16 mile from the runway and 25 feet tall; middle bars were 1/4 mile from the runway, 100 feet tall; outermost bars were 1/2 mile from the runway, 200 feet tall. The bars were arranged in ascending height so that the tops of the bars defined the proper glidepath, forming a highway in the sky. Simultaneously lining the tops of all the bars with the viewer's eyes placed the subject on the proper glidepath of 4.3 degrees. As the approach was flown, the tops of the bars corresponded to the altitude the subjects should be flying as the bars are passed. Subjects were instructed to climb or descend as required to keep the tops of the bars lined with their eyes (see Figure 4).
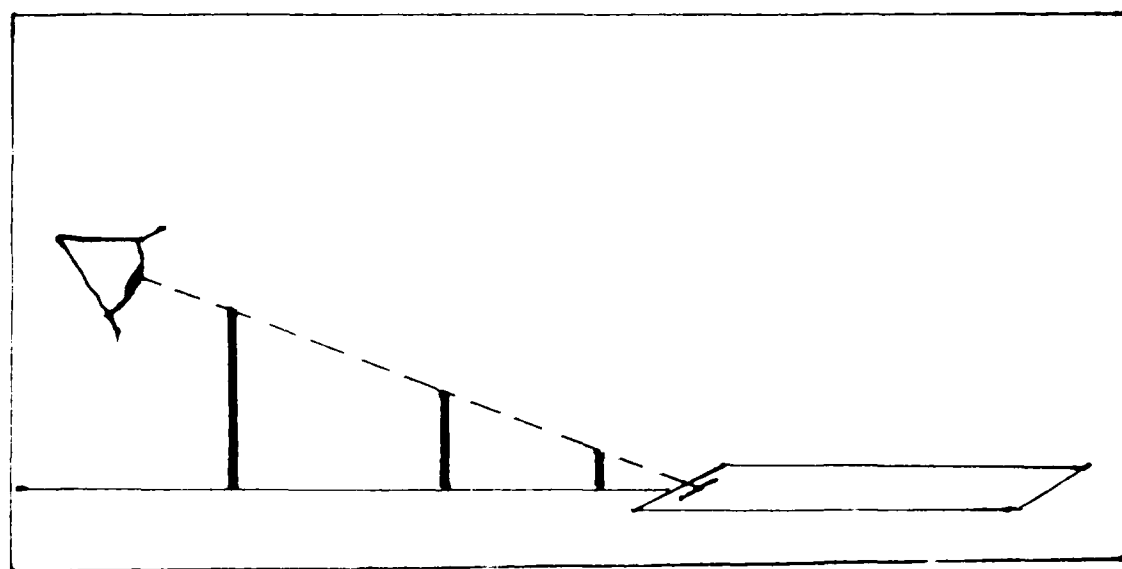

Figure 4. Depiction of subject sighting along the tops of vertical glidepath cues to establish proper angle.

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The cue presented for heading control was simply an extension of the runway centerline, to a distance one-half mile beyond the actual runway, under the approach path. The extended centerline provided a more salient cue for determining lateral position in relation to the runway.

The Adaptive Feedback Groups practiced with the same display as the Constant Augmented Feedback Groups, except that the glidepath cues and extended centerline appeared only if and while the subjects' flight performance deviated outside a specified criterion envelope. The extended centerline appeared on the screen whenever the aircraft position deviated laterally more than 1.5 degrees plus 50 feet either direction from runway centerline.

The glidepath cues switched on when aircraft position exceeded 0.5 degrees plus 13.7 meters above, or 0.5 degrees plus 7.8 meters below the proper 4.3 degree glidepath. If flight inside the proper envelope was again established, the cues were switched off. The switching of the centerline cue and the glidepath cues were independent in that glideslope cues could be present without the extended centerline and vice versa. During a typical early trail, performance was such that the cues rem ed on most of the time.

In the final session, in which transfer was measured, all subjects flew a block of 20 trials in the non-augmented, or control condition.

Performance Measures

The performance measure most suitable for this study was root mean square (RMS) error about the flight path. Data were collected separately for lateral displacement error and vertical altitude error. In addition, the approach path was broken into two segments in an effort to compare the utility of the augmenting cues very close to the runway to the utility of the cues at the beginning of the approach. Summary RMS error measures were recorded separately for the first half mile of the approach, the last half mile of the

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approach, and then for the overall approach. Therefore, six RMS measures were taken on each trial, Lateral Overall, Lateral 1st Half, Lateral 2nd Half, Vertical Overall, Vertical 1st Half, and Vertical 2nd Half.

Results

Training Trials

Repeated measures analyses of variance were performed on each of the six

dependent measures. For all of the dependent measures, no two instructional

methods groups were significantly different at the 0.05 level. In fact, $p =$

0.15 was the closest any of the measures came to significance during the

training trials. The results for training trials were further broken down

into trials 1 through 20, in which all 48 subjects participated, and trials 21

through 40, in which only 24 of the subjects continued training. Results of

the analyses are shown in Tables 1 & 2.

From the repeated measures analysis of variance, the effect of Trial was

significant in several of the measures, indicating that some learning occured

during training. Specifically, learning was significant at $p < 0.05$ for the

first 20 training trials in Lateral-1st half, and all three Vertical measures;

significant at $p. < 0.05$ for the second 20 training trials in Lateral-Overall,

Lateral-1st half. Measures were also significant between $p. = 0.05$ and

$p. = 0.06$ for four others. These data are summarized in Table 3.

The learning performance data, Figures 5 & 6, reveal how performance in

all groups improved with practice for the Overall dependant measures.

Improvement was slow but steady. It cannot be concluded from the data that

performance had stabilized at an asymptotic level by the end of the training

trials. Subjectively, it should be noted that none of the groups achieved

very good performance in the landing task.

Transfer Trials

Repeated Measures Analyses of Variance were performed on each of the six

dependant measures in the transfer trials data. Again, as in the training

data, no two groups were significantly different at the 0.05 level. The

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Table 1

From Repeated Measures Analysis of Variance

Probabilities that there were no differences between
Instructional Methods for the six dependent measures
during Training

Training Session 1. Trials 1 - 21

Lateral - All   p. = .96
Lateral - 1st Half   p. = .77
Lateral - 2nd Half   p. = .96

Vertical - All   p. = .24
Vertical - 1st Half   p. = .15
Vertical - 2nd Half   p. = .27

(no two groups significantly different for any of the six measures)

_____

Training Session 2. Trials 21 - 40

Lateral - All   p. = .57
Lateral - 1st Half   p. = .44
Lateral - 2nd Half   p. = .58

Vertical - All   p. = .15
Vertical - 1st Half   p. = .40
Vertical - 2nd Half   p. = .15

(no two groups significantly different for any of the six measures)

Table 2

Summary Root Mean Square (RMS) error measures in degrees

Training Trials 1 - 20

Vertical Measures

	All	1st Half	2nd Half
Control	2.44	.77	3.29
Supplementary	2.18	.72	2.93
Adaptive	1.93	.61	2.60

Lateral Measures

	All	1st Half	2nd Half
Control	2.75	.57	3.80
Supplementary	2.70	.53	3.74
Adaptive	2.60	.53	3.59

Training Trials 21 - 40

Vertical Measures

	All	1st Half	2nd Half
Control	2.00	.70	2.67
Supplementary	1.11	.53	1.44
Adaptive	1.72	.67	2.28

Lateral Measures

	All	1st Half	2nd Half
Control	1.4	.25	1.93
Supplementary	1.12	.22	2.19
Adaptive	1.79	.35	2.47

Table 3

From Repeated Measures Analysis of Variance

Main effect of Trial

Probabilities that there were no differences between
trials during training for the six dependent measures

	Training Block 1 Trials 1 - 20	Training Block 2 Trials 21 - 40
Lateral Measures		
All	p. = 0.06	p. = 0.05
1st Half	p. = 0.001	p. = 0.001
2nd Half	p. = 0.075	p. = 0.063
Vertical Measures		
All	p. = 0.003	p. = 0.057
1st Half	p. = 0.001	p. = 0.797
2nd Half	p. = 0.005	p. = 0.056

LATERAL MEASURES

Figure 5. Learning curves for Lateral – Overall measure, for the three
instructional method groups, depicting root mean square error as a function
of 5 trial means for training and transfer.
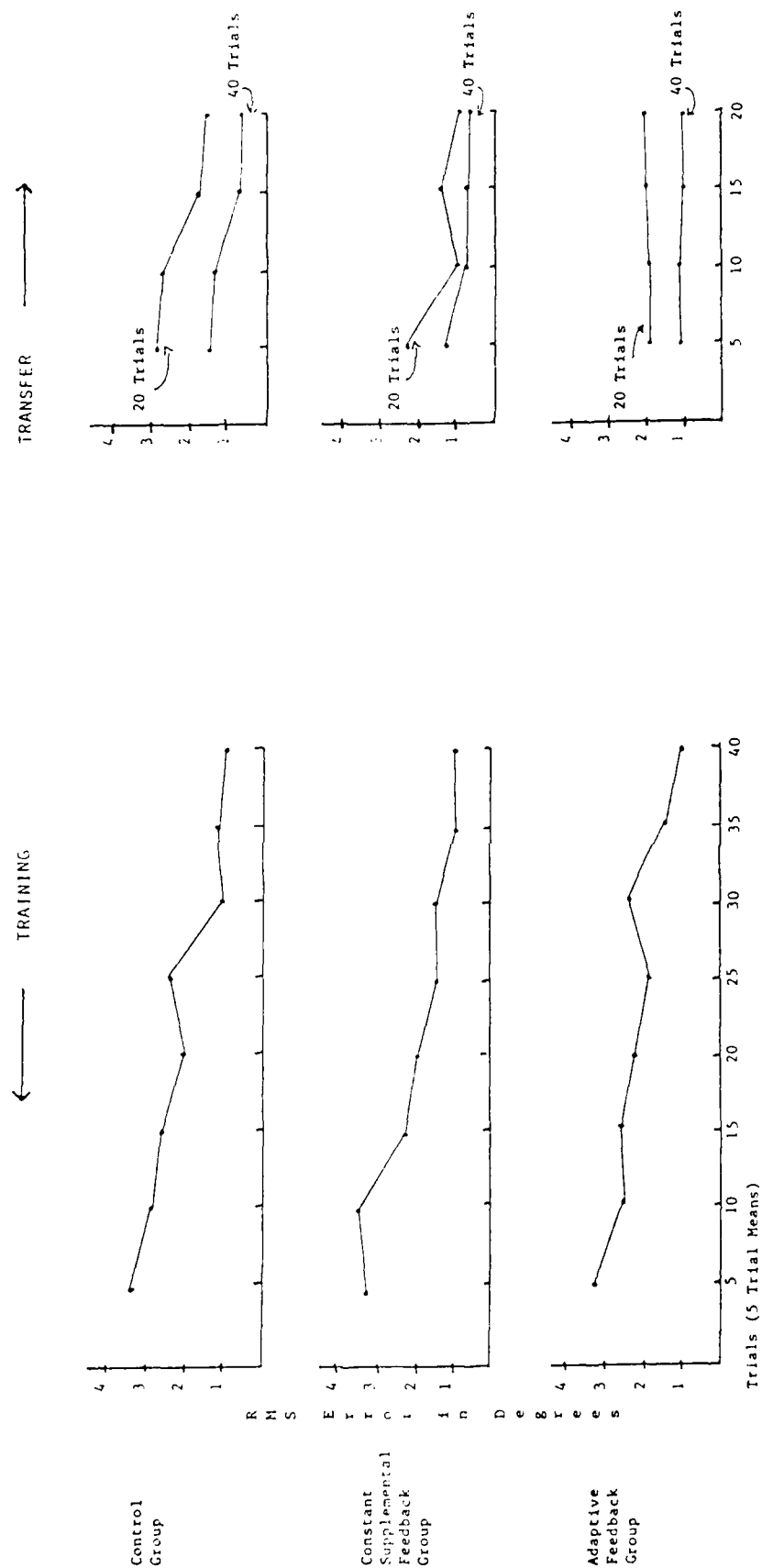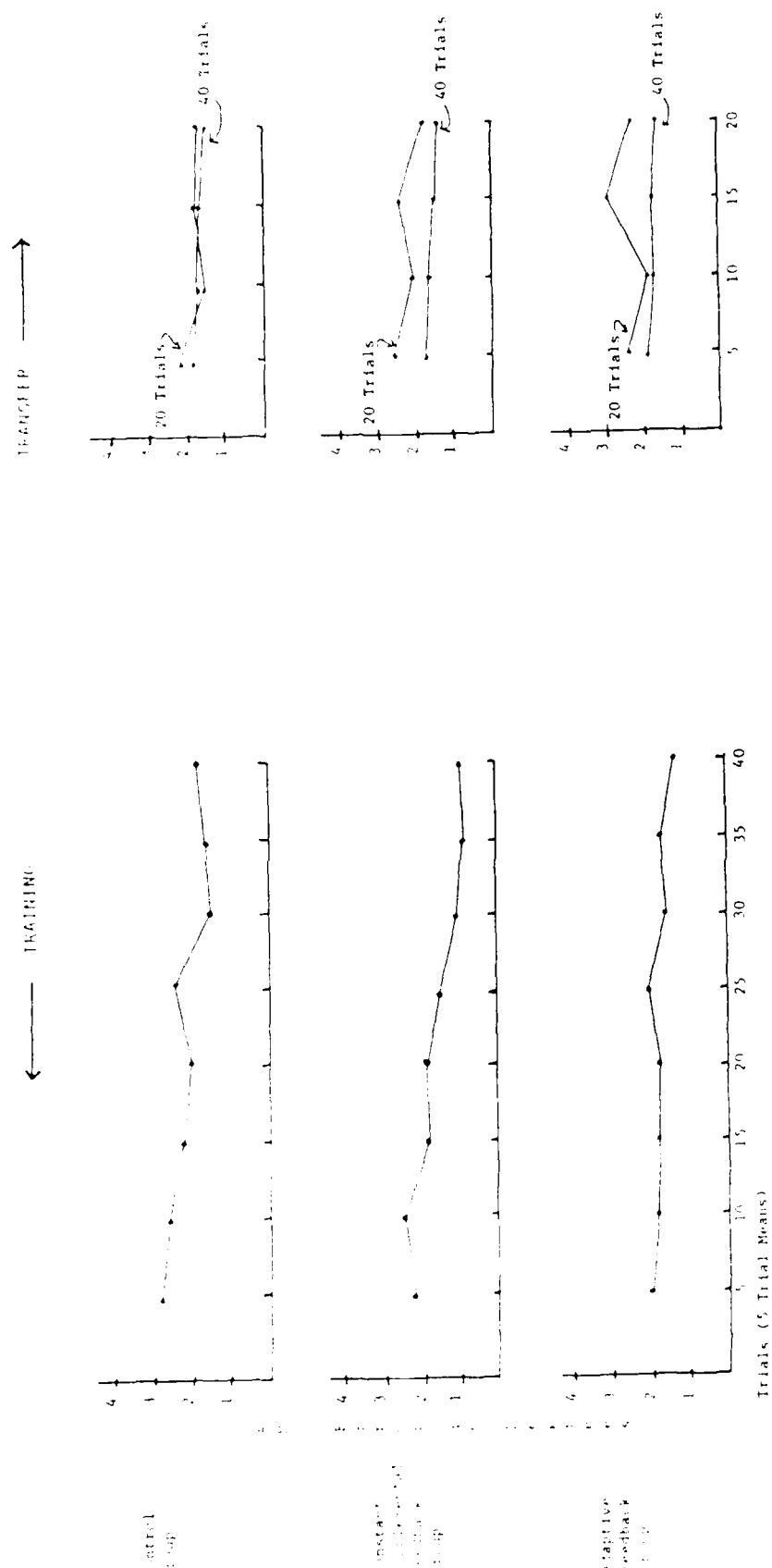
VERTICAL MEASURES

Figure 6. Learning curves for Vertical – Overall measure, for the three
instructional method groups, depicting root mean square error as a function
of 5 trial means for training and transfer.

results of the analyses are reported in Tables 4 & 5. There was an effect, however, of length of training. All three lateral dependant measures demonstrated a significant difference in transfer performance between 20 trials of training and 40 trials of training, with the longer training period resulting in the best performance in each case. The effect of length of training was only marginally significant in the three vertical measures (see Table 4). Finally, there were no two way interactions between length of training and training condition ($p > 0.3$).

Covariate

Performance on the video game was not found to be useful as a covariate in this study and was not used in the final data analysis. Correlations between the measure and the dependant measures of the six groups covered a wide range, but were generally low. However, given the fact that this study failed to find significant differences between treatment groups on any of the dependant measures, caution should be exercised in concluding that the measure is not a good covariate for computer-based landing training.

Table 4

From Repeated Measures Analysis of Variance

Probabilities that there were no differences between
the two conditions for the six dependent measures
during Transfer

Main Effect of Instructional Method:

Lateral - All   p. = .45
Lateral - 1st Half   p. = .40
Lateral - 2nd Half   p. = .46

Vertical - All   p. = .61
Vertical - 1st Half   p. = .64
Vertical - 2nd Half   p. = .63

(no two groups significantly different for any of the six measures)

Main Effect of Length of Training: (20 training trials versus 40
training trials)

Lateral - All   p. = .006
Lateral - 1st Half   p. = .001
Lateral - 2nd Half   p. = .007

(significant for all three Localizer measures: 40 training trials
superior to 20 training trials)

Vertical - All   p. = .092
Vertical - 1st Half   p. = .84
Vertical - 2nd Half   p. = .07

(no two groups significantly different for any of the Localizer
measures)

Table 5

Summary Root Mean Square (RMS) error measures in degrees

Transfer Session (Twenty Trials)

	Training Trials	Vertical Measures All	1st Half	2nd Half
Control	20	1.90	.64	2.56
	40	1.82	.65	2.43
Supplementary	20	2.16	.71	2.93
	40	1.57	.59	2.09
Adaptive	20	2.39	.64	3.27
	40	1.84	.80	2.40

	Training Trials	Lateral Measures All	1st Half	2nd Half
Control	20	2.28	.53	3.14
	40	1.01	.17	1.39
Supplementary	20	1.45	.33	2.01
	40	.95	.20	1.31
Adaptive	20	2.12	.46	2.92
	40	1.13	.26	1.55

Discussion

The Personal Computer in Simulation

As expected, the personal computer was capable of supporting most of the hardware and software requirements of a general aviation simulator. Storage capacity was more than ample to collect large amounts of performance data. In fact, although approximately 36K bytes of data were recorded for each subject, additional storage capacity was available for many more times the amount collected here. This suggests that even more elaborate data collection programs are possible on personal computers if required.

Another important plus for the personal computer in simulation is the fact that most data analysis can be accomplished on the same equipment that drives the simulation and collects data. Popular statistical packages are now available for personal computers with the identical power and capacity of mainframe computer packages. Data can be collected on the personal computer, formatted directly for use by the statistical package, and analyzed at the same work station. With properly designed data collection software programs, the experimenter need never manipulate data manually or enter individual data points into statistical programs.

As predicted, personal computers are limited in their ability to support the simulation in terms of visual display generation and vehicle dynamics. The degree of success depends directly on the complexity of the simulation required, but in general, complex visual displays exceed the capabilities of personal computers. In situations where visual scenes require a rich environment of texture and objects, high frame rates for adequate animation are probably not possible. However, if the simulation requires very simple monochrome scenes that are skeletal with few lines needed to draw the display, adequate frame rates are likely.

The personal computer industry continues to experience rapid growth.

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Technology and processing speed available on mainframe computers today are likely to make their way to the personal computer market in the future. Therefore, these comments on the limitations of personal computers in simulation will likely be invalid soon, to the obvious advantage of the general aviation training community.

The Personal Computer in Training

The results of this study show that learning can occur in personal computer-based training devices. The training community has been using large computers in simulation for years with great success. While fidelity, methodology, and the amount of learning that takes place in simulation remains at issue, few argue that computer simulation can, if designed and used properly, promote learning. The question had to be asked whether the successes found in traditional mainframe computer simulators would survive in personal computer-based simulators. Modest learning trends were found in many of the measures in the training blocks. Furthermore, strong effects were found in several of the measures when subjects trained twice as long prior to transfer testing. This study, along with others such as Lintern and Weinstein (1987) and Trollip (1977) show that effective training can be accomplished on PC-based devices.

Using PC-Based Simulators to Enhance Training

Nonsignificant differences between experimental conditions in this study were unexpected. Although the same theory suggested both Lintern's (1980) hypothesis and the hypothesis examined here, Lintern's study yielded significant results. The differences in results may be due either to experimental error or to differences between the two studies which were thought to be irrelevant. A close examination of experimental design, control, and execution satisfactorily eliminates experimental error as a

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possible cause for contaminated data. However, examining differences between the two studies may provide insight into the results reported here.

An examination of performance curves suggests that much less learning took place during the blocks of training than was expected or desired. Direct observation of the subjects during the experiment revealed considerable confusion in operating the apparatus. Even towards the end of training, most subjects were still unsure of proper control/diplay relationships, and were limited in their ability to interpret vehicle motion trends and the resultant corrective action required. In particular, subjects were prone to make control reversal errors, in which a perceived need to correct in one direction resulted in a control action to move in the other direction. Control reversals were not reported by Lintern in the literature. Furthermore, personal communication, March 12, 1987 with G. Lintern confirms that such behavior was rare in his study. Performance curves show slow improvement, but stable, reliable performance was not achieved by any of the groups. Overall, the data suggest that the subjects did not become proficient at performing the task in any of the conditions.

In attempting to explain the poor learning, some possible explanations may be offered. Perhaps the task itself was too difficult to learn in some way, or (/and), insufficient training was provided to reach a level of skilled performance.

Although the task was in theory identical to the landing task used by Lintern, there were physical differences in the experiment. Lintern used a video projector to present the landing display on a large screen well in front of the subjects. The screen was 70 inches by 53 inches in size, placed 88 inches in front of the subject's viewing position. The display subtended 43 degrees of visual angle in the subject's field of view. In the present experiment, a color computer monitor was used with 10.5 inch by 7.5 inch

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measurements placed 18 inches in front of the subject, subtending 32 degrees of visual angle in the field of view. The implications for the human visual system may be quite different between these two display presentations.

According to the work of Leibowitz and Dichgans (1980), and others (Brandt & Leibowitz,1978; Leibowitz & Owens,1977; Leibowitz, Shupert & Post,1983), there are actually two visual systems operating simultaneously in visual perception. Focal vision is mediated primarily by the central retina and provides form perception and identification, while ambient vision is mediated primarily by the peripheral retina and provides information regarding spatial localization and orientation. Focal vision, then, answers the question of what is there, while ambient vision answers where.

Incongruence of orientation and motion cues presented to the two visual systems has been implicated in the phenomenon of simulator motion sickness and in disorientation (Leibowitz, Shupert & Post, 1983). When motion cues presented to the focal system are contrary to orientation cues presented in the ambient field, disorientation results. Only a small step must be taken to propose that confusion and disorientation of this type might have occurred with subjects viewing the display in the present experiment. By trying to represent the entire visual field on a small screen, cues normally found in and processed by the ambient system are forced into the focal system. In addition, while cues in central vision are conveying motion information, cues in the periphery are sending the message that there is no motion. Although proponents of the two visual system theory cannot agree exactly where central vision stops and peripheral vision begins, the differences in field of view between Lintern's and the present display may account for at least some of the data reported here if there is an important distinction between 32 degrees and 43 degrees of visual angle in the field of view.

As Leibowitz and other proponents of the dual visual system point out, disorientation in aircraft under instrument conditions may result from the substitution of an unnatural symbolic indicator to replace the visual stimuli normally involved in orientation. Also implicated is the failure of a presumed learned cognitive skill to compensate for mismatched signals.

In the present experiment, subjects were exposed to a display similar to the standard inside-out display of aircraft artificial attitude indicators. Such indicators attempt to represent orientation and movement from an ego centered perspective, where operators view themselves as stationary in space, while the visual world moves about them. With an inside-out display, if the aircraft, and the subject inside, rotate clockwise as in a right turn, the world must appear to move counterclockwise for one to consider themself stationary. In fact, if such clockwise motion were viewed through a small porthole in the nose of the aircraft, the world would indeed appear to rotate counterclockwise. While geometrically correct, representing the world this way is contrary to an importatnt principle of display design.

According to Roscoe's (1968) Principle of the Moving Part, operators expect a consistent mapping between what is moving on the display and what is moving in the real world. As in the above example, banking the aircraft to the right, generating a clockwise rotation in the subject's internal model of what is happening to him, produces a counter-clockwise rotation of the moving element on the display, the horizon line. To the subject, it seems counterintuitive that moving the control right should cause the display to move left. Not only is the representation unnatural, the novice subject possesses no skill to compensate for the mismatched cues. Such a skill can be learned, as generations of pilots throughout the world have proven. However, acquiring the skill needed to fly by reference to instrumentation that violates the principles of display design takes considerable training. The

flight naive subjects in the present study probably did not have the time necessary to develop the needed skill.

Lintern's (1980) subjects were flight naive also, yet his study was not affected by these problems. Since Lintern's landing display was projected onto a large screen, orientation cues were more likely to stimulate the ambient visual system, where such cues are optimally processed. Leibowitz, Shupert and Post (1983) further point out that ambient functions are optimized the larger the area of the visual field stimulated. Therefore, a large, wide visual display, stimulating a large portion of the visual field, is better for tasks requiring spatial orientation than a small display that lies primarily in the focal visual field.

If the argument for two visual systems is valid, display size and field of view can have critical impact on simulator visual display design configuration. For instance, small displays seem satisfactory for simulated instrument training, where spatial orientation is not as important and the information required is best presented to the focal system. For tasks such as landing and contact flying that rely heavily on motion perception and spatial orientation, large displays may be needed to ensure proper stimulation of the ambient system in peripheral vision. While experienced pilots with instrument training might have performed adequately on the apparatus used in this study, it is probable that the use of a small screen display for teaching landing skills renders the task too difficult for novice trainees.

Another major difference between Lintern's study and the present one concerns the type and amount of training given to the subjects prior to experimentation. Both studies provided approximately the same amount of training trials, but Lintern included significant aviation contextual ground training and simulator training prior to experimentation.

One explanation for the confusion and high control error rate found in this study may be an underestimation of the motor component in the overall flying skill. This approach-to-landing task tested the subject's ability to perceive the correct runway approach path. However, making a response to the task required subjects to control the apparatus and fly the simulator to a point that represents a response. Thus, the task itself had both a perceptual and a motor component. Aviation researchers have diverse positions on whether flying is a perceptual skill, a motor skill, or some combination of the two. Although the role of motor skill in flying is unresolvable in this study, perhaps some insight can be gained by examining how differently motor learning was treated here and in Lintern's work.

In Lintern's study, subjects were provided ground training material and given homework assignments on a wide range of aviation related topics such as flight theory, aircraft systems, and aircraft handling characteristics. Following ground preparation, each subject received exposure to the simulator to be used in the experiment. Subjects practiced the proper techniques for aircraft control to include straight and level flight, turns, climbs, descents, and flight with reference to instruments. After pre-training, the experimental paradigm was introduced and data collection began.

In the present study, no pre-training instruction was given nor did subjects receive an opportunity to fly the simulator prior to the experiment. The decision to exclude pre-training in the study was motivated by two considerations. First, it was thought that the task and the experimental apparatus was sufficiently simple and straightforward to eliminate the need for extensive training. The paradigm and flight controls were constructed to reduce the task to simple two-axis tracking. By eliminating as much aviation dependant context as possible in task and equipment construction, it was hoped that the findings could be generalized to perceptual-motor tasks outside of

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aviation as well as within aviation.

Secondly, part of the rationale for developing the landing trainer was to assess its utility in light aircraft flight training. Such an inexpensive training device might be of great benefit early in the flight training program if it could help students internalize the geometric shape of the runway when on the proper glidepath. The use of the trainer for this purpose would be front loaded at the beginning of training. Students would spend several sessions on the landing trainer before their first flight in the aircraft. Perceptual learning of geometric relationships accomplished in the trainer would save time and money when compared with trying to learn the same things in the aircraft. In this context, it was natural to attempt to train subjects in the present study as if they had received no prior training in the aircraft. The landing trainer was intended to be their first exposure to flight training.

If, however, there is a large motor component to flying, subjects in the present study may have been unable to attend to the perceptual portion of the task due to saturation by the motor requirements. The conclusion to be drawn concerning motor skill pretraining may be that although perceptual skills are necessary to flying, some level of motor skill proficiency is beneficial as a prerequisite to introducing the perceptual component. The PC-based trainer might better be employed by training basic aircraft control skills, then introducing a perceptual skill such as the approach-to-landing task.

Transfer to the Operational System

The clearest test of a training technique, methodology, or experimental manipulation is a test of transfer to the operational device. In this study, as in most aviation studies, resources were not available to make an in-flight test of transfer possible. However, positive results from those in-flight

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transfer-of-training studies that do exist, such as Lintern (1980), suggest that it is worthwhile to continue to examine promising ideas in simulator-to-simulator studies. Concepts that prove themselves in the simulator should be considered for in-flight investigation.

It is clear that subjects did not learn as much about landing the simulator as intended. The high occurence of confusion was also not anticipated. However, without attempting to measure transfer in an in-flight validation study, it cannot be concluded that learning accomplished in this landing trainer will not transfer. It would be easier on face value to expect transfer had the learning effects in the trainer been more compelling. Nonetheless, the promise of effective transfer remains, as evidenced by Lintern (1980). Efforts should be directed at finding ways to promote better learning in the training simulator. Transfer should follow.

Finally, the lack of statistical differences between experimental groups was not expected. Although the cue logic for the Supplemental Groups and the Adaptive Groups was designed differently, it seems that functionally, the two became equivalent. The arguments presented earlier suggest that the task was too difficult for the subjects because of visual angle problems, display design considerations, and insufficient motor skill. If these argumemnts are correct, and subjects never attained proficiency, the cue logic in the Adaptive Groups would present the cues most of the time. Therefore, the two displays would function identically for both groups. If subjects from both experimental groups experienced the presence of the cues during most of the trials, little difference could be expected. Furthermore, it is possible that frequent off-and-on switching of the cues in the Adaptive Groups might have added additional display clutter and confusion to the task.

Conclusion

The results of this study do not support the use of the landing trainer as the first exposure to flying, at least not in the same manner attempted here. It is apparent from the work done here that flying an aircraft cannot be reduced to simple two-axis tracking. Exposure to the principles of aircraft control, such as employed by Lintern, are evidently needed to afford students enough control of the aircraft before learning of any specialized tasks, particularly perceptual, can begin.

The landing trainer may yet find a place in the flying training community. The theory that suggests the feasibility of teaching physical and geometric relationships, system dynamics, and perceptual interdependancies remains sound. Perhaps this study has shown that it matters as much the way a promising technique is used as it does which technique is used. Further, these findings suggest that optimum display size and design are dependent on the task to be accomplished. Next generation research in simulator visual systems should determine the role of peripheral vision in contact flying manuevers such as take-off, landing, formation, aerial refueling, low-level flying, and weapons delivery, while addressing improved cue selection and presentation.

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